ELECTRICAL INSULATION CHARACTERISTICS OF PP/EPDM BLENDS WITH AlN, Al_2O_3 AND ORGANOCLAY NANOFILLERS

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by

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LIST OF ABBREVIATIONS

PP	Polypropylene
EPDM	Ethylene propylene diene monomer
SiR	Silicone rubber
DCP	Dicumyl peroxide
IEC	International Electrotechnical Commission
AC	Alternating current
LC	Leakage current
HTV	High temperature vulcanized
LMW	Low Molecular Weight
ATH	Alumina trihydrate
DC	Direct current
UV	Ultraviolet
PTFE	Poly-Tetra -Fluoro-Ethane
LDPE	Low density polyethylene
HV	High voltage
ER	Epoxy resin
SEM	Scanning electron microscope
USB	Universal Serial Bus
XLPE	Crosslink polyethylene
AlN	Aluminium nitride
Al_2O_3	Aluminium oxide
ZnO	Zinc oxide

SiO_2	Silicone oxide
BN	Boron nitride
TiO_2	Titanium oxide
NH_4Cl	Ammonium chloride

LIST OF SYMBOLS

vol %	Percentage
kV	Kilovolt
Hz	Hertz
°	Degree
Ω	Ohm
wt. %	Weight percent
ml/min	Milimitre per minute
A	Ampere
mm	Milimitre
Hz	Hertz
K	Kelvin
kV/mm	Kilovolt per milimetre
ε_c	Permittivity

CIRI-CIRI PENEBATAN ELEKTRIK BAGI CAMPURAN PP/EPDM DENGAN NANOPENGISI AlN, Al_2O_3 DAN ORGANOCLAY

ABSTRAK

Kegagalan penebat akibat penuaan atau pencemaran adalah punca utama gangguan talian. Apabila permukaan penebat tercemar di bawah keadaan basah, lapisan permukaan menjadi konduktif dan menyebabkan kebocoran arus lapisan. Penebat yang terdedah kepada arus bocor akhirnya akan mengalami kerosakan yang teruk. Baru-baru ini, penebat luar diperbuat daripada kaca atau porselin yang digunakan dalam sistem kuasa sejak dahulu lagi semakin diganti dengan penebat polimer. Oleh itu, banyak penyelidikan mengenainya telah dijalankan dalam penebat polimer terutamanya PP / EPDM. Walaupun kajian mengenai PP / EPDM telah dijalankan, setakat ini tidak ada kajian yang dilaporkan pada sifat dielektrik dan hakisan dengan pelbagai pembebanan pengisi campuran PP / EPDM. Oleh itu, dalam projek ini, siasatan terhadap sifat dielektrik dan hakisan untuk menjejaki campuran PP / EPDM telah dijalankan dengan tiga jenis nano pengisi seperti Al_2O_3, AlN dan organo. Peratusan pengisi muatan bagi setiap spesimen adalah 2%, 4%, 6% dan 8% vol. Kesan Al_2O_3, ALN dan organo nano pengisi dengan pelbagai muatan pada sifat dielektrik, hakisan untuk pengesanan, kekonduksian terma dan kekalisan campuran PP / EPDM telah diujikaji. Hasilnya menunjukkan bahawa penambahan 2 vol% daripada Al_2O_3 dan organoclay nano pengisi ke dalam campuran PP / EPDM telah meningkatkan kekuatan dielektrik dengan 4.13% dan 4.33% masing-masing berbanding campuran tanpa nano pengisi. Di sisi lain, AlN telah menurunkan kekuatan dielektrik campuran PP/ EPDM sebanyak 1.79%. 2 vol% daripada nanokomposit Al_2O_3 yang mempunyai pemalar dielektrik sedikit sama dan kekuatan

dielektrik yang lebih tinggi. Keputusan menunjukkan bahawa penambahan nano pengisi bertambah baik bagi hakisan untuk pengesanan. Kehilangan jisim dan hakisan kedalaman PP / EPDM menurun dengan peningkatan dalam pembebanan pengisi. PP / EPDM yang diisi dengan 4 vol% organo dan 6 vol% Al_2O_3 dan ke atas dianggap mempunyai permukaan hidrofilik. PP / EPDM dengan AlN nano pengisi mengurangkan keadaan kekalisan bahan apabila kepekatan pengisi yang meningkat dan mengekalkan keadaan permukaan kekalisan pada 8% vol.

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ABSTRACT

Insulator failure as a result of ageing or contamination flashover is the major cause of line outages. When the surface of an insulator is contaminated under wet condition, the surface layer become conductive and caused leakage current to flow on the layer. The insulator exposed to the leakage current will eventually experience a severe damage. Recently, the outdoor insulation made from glass or porcelain which is used in power system since long time ago have gradually replaced with polymeric insulators. Thus, many research has been conducted in polymeric insulators mainly PP/EPDM. Although the research on the PP/EPDM has been carried out, so far there are no reported studies on dielectric properties and resistance and erosion to tracking with various filler loading of PP/EPDM blends. Thus, in this project, the investigation on dielectric properties and resistance and erosion to tracking of the PP/EPDM blends with three types of nanofillers such as Al_2O_3, AlN and organoclay was carried out. The percentage of filler loading for each specimen is 2 vol%, 4 vol%, 6 vol% and 8 vol%. The effects of Al_2O_3, AlN and organoclay nanofillers with various loading on dielectric properties, resistance and erosion to tracking, thermal conductivity and hydrophobicity of PP/EPDM blends were experimentally investigated. The result revealed that the addition of 2 vol% of Al_2O_3 and organoclay nanofillers into the PP/EPDM blend has increased the dielectric strength by 4.13% and 4.33%, respectively from that without nanofiller. In the other hand, the AlN has decreased the dielectric strength of PP/EPDM blends by 1.79%. The 2 vol% of Al_2O_3 nanocomposites has slightly same dielectric constant and

higher dielectric strength with the unfilled PP/EPDM. The results revealed that addition of nanofillers significantly improved the resistance and erosion to tracking. The mass loss and erosion depth of the PP/EPDM nanocomposites decreased with the increase in filler loading. The PP/EPDM filled with 4 vol% organoclay and 6 vol% Al_2O_3 odward is considered to have hydrophilic surfaces. The PP/EPDM with AlN nanofiller reduces the hydrophobicity condition of the material when the concentrations of the filler increased and maintained the hydrophobic surface condition at 8 vol%.

CHAPTER 1

INTRODUCTION

1.1 Overview

The generation and consumption of electric power are seldom in close vicinity. Electric power can be transmitted through overhead lines from the generating sites to the distribution line. Most of these lines span over several thousands of kilometers. In order to minimize losses, power is transmitted at higher voltages in the order of several hundred kilovolts. The high voltage line conductor has to be physically attached to the tower support structure which is at ground potential. For the purpose of electrically isolating these line conductors from the support structure as well as providing mechanical support to them, insulators are used (Gorur et al. 1999).

Most of the insulators are often under high electrical as well as mechanical stress. The ever increasing demand for electrical energy worldwide has lead to the use of even higher system voltages for power transmission. Higher voltage rating puts the insulators under a large amount of electrical stress. In addition to that, the high voltage insulators used in outdoor applications are degraded by various environmental factors including precipitation, winds, temperature variations and pollution. Under wet and polluted conditions, the electric field along their length gets intensified which might lead to flashover. Flashover of insulators in service could give way to interruptions in power supply which affects the reliability of these bulk systems. Also, interruptions could incur heavy monetary losses to many customers and industries. It is important to avoid flashovers from occurring by regular checking of pollution deposit on every insulator and cleaning or replacement of dusty or faulty insulator. It is however very difficult to check energized insulators due to their height, voltage across them, and their location. Transmission lines pass through mountains, terrains, and horrible places (Syakur & Berahim 2012). Therefore, the insulator must be high relative permittivity in order for the dielectric strength to remain high, high ratio of puncture strength to flashover and also hydrophobic surface to withstand in wet environment.

The outdoor insulation string has always being made from glass or porcelain since long time ago and many researchers are trying to reduce the drawback of these insulators types. Polymeric insulators offer many advantages such as light in weight which can reduce cost, reduce the chance of breakage, hydrophobic in nature which can reduces transmission losses and higher tensile strength compared to porcelain insulator. Continuous efforts were made to improve the polymeric insulators since 1970s (Ehsani et al. n.d.). Figure 1.1 illustrates the example of the polymeric insulator used in transmission lines.

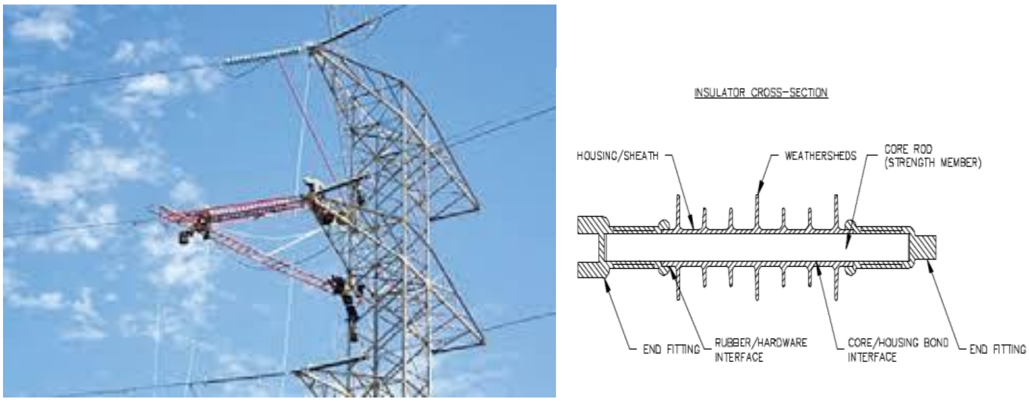

Figure 1.1: Polymeric Insulators

Today, the most commonly used polymeric materials for high voltage applications are Silicone Rubber (SiR), Ethylene Propylene Rubber (EPR), and Ethylene Propylene Diene Monomer (EPDM) (Naidu et al. 2009). SiR samples with hydrophobic surfaces have discrete water droplets rather than thin film of water on their surfaces under moist conditions (rain, fog etc). Therefore, the insulator provides a high resistance path to the flow of leakage current. This helps in reducing the probability of flashover. EPDM is also a preferred material for the application of electrical insulation because it composes of excellent electrical properties, flexibility in a wide temperature range, and resistance to moisture and weather (Ehsani et al. 2004; Nasrat & Sharkawy 2007). Although SiR, EPR and EPDM have been widely used as insulator in power industry, however, many effort are still going on to further improve their insulation performance. In the work reported by Prabu et al (Prabu et al. 2007), they revealed that the mechanical properties of SiR and EPDM blends can be improved and do not cause significant reductions in any electrical properties. Mixture of commodity polymer, Polypropylene (PP) with EPDM could reduce the production cost because EPDM alone is very expensive compared with the other conventional elastomer (Ismail & Akil 2005). The PP/EPDM blends have been utilized widely as an insulator for several decades in various industrial areas. Since mixing PP in any ratio is possible, a wide spectrum of materials is obtained, from elastified PP to EPDM rubber reinforced with thermoplastic (Arroyo et al. 2000; Fernando & Gubanski 2000; Öksüz et al. 2006)

Most of the researchers have been reported on the mechanical properties (Öksüz et al. 2006; Reza et al. 2007; Barkoula et al. 2008), rheology (Ismail & Akil 2005; Bouchart et al. 2008) and morphology of PP/EPDM blends (Reza et al. 2007; Bouchart et al. 2008). In order to increase the insulator's performance, nanotech filler were been introduce. Nanotechnology, sometimes shortened as 'nanotech', deals with the manipulation and manufacturing of structures of which at least one of the dimensions is less than 100 nanometers (Of et al. 1998). As many improvements in material properties are been exploit from using nanocomposites, a lot of electrical properties are also seen to have been enhanced making use of nanocomposites. There are several results from previous research shows an enhancement of electrical properties using nanocomposites. One of the significant advantages of using nanoscale fillers instead of micrometer-scale fillers may be an increase in the breakdown strength. Bearing this finding in mind, many researchers around the world have been focusing to find the better fillers that can increase the dielectric properties of polymeric insulator. As reported by Hamzah et al, organoclay nanofiller gives the highest result in dielectric strength of PP/EPDM followed by aluminium oxide (Al_2O_3) nanofiller (Hamzah et al. 2014). Venkatesulu et al (Vas et al. 2012) also reports that the addition of 4% by wt of nano alumina composite showed the erosion performance is equivalent to the 30% by wt of micro ATH composite. They are also observed that the erosion performance of nanocomposite is attributed to its better thermal stability. This result obtained provides new ideas for continuing research with both filler and aluminium nitride (AlN) since the AlN has high thermal conductivity (Cao et al. 2004).

From this point of view, the resistance and erosion to tracking of nanocomposites should be further investigated to gain additional knowledge of the nanocomposite dielectric properties. This can be a reference for the development of new insulating materials. In this project, investigation of dielectric properties, resistance and erosion to tracking, contact angle and thermal conductivity of PP and EPDM were evaluated with three types of nanofiller with various percentage of filler loading. The blending ratio 50:50 of PP/EPDM is selected because it possesses balanced electrical and mechanical properties. Nanofillers that used in this project were Al_2O_3, AlN and organoclay. Vulcanizing agent dicumyl peroxide (DCP) was added in the blending as a curing agent to enhance the breakdown strength and also as a cross-linking agent in the PP/EPDM system (Reza et al. 2007).

The results of this investigation would contribute to new ideas in producing better insulation properties of polymeric blends and generate development in electrical insulating systems in current situation. This investigation also would provide better understanding towards dielectric properties and resistance and erosion to tracking of PP/EPDM polymeric insulators. In addition, it is useful as guidance and references in designing a new outdoor application that suitable in tropical area such as Malaysia.

1.2 Objectives

The objectives of this research are:

i. To study the effect of nanofiller loading on the thermal and electrical insulation properties of PP/EPDM nanocomposites

ii. To compare dielectric strength of PP/EPDM with three types of nanofillers (aluminium oxide, aluminium nitride and organoclay)

iii. To investigate the resistance and erosion to tracking of PP/EPDM nanocomposites

1.3 Scope of Project

This project mainly focuses on the investigation of the dielectric properties and the effect of the resistance and erosion to tracking of PP/EPDM with and without filler. The investigation of dielectric strength and the resistance and erosion to tracking was carried out based on IEC 60243 standard and IEC 60587 standard, respectively (Motors & Store 2011). In this project, three types of nanofiller were chosen namely Al_2O_3, AlN and organoclay. The experiment for dielectric strength and resistance and erosion to tracking were conducted in Power laboratory by using AC high voltage power system while the test for contact angle and thermal conductivity are conducted in Material and Chemical of Engineering School. The data collected were being discussed and analysed.

1.4 Outline of reports

This thesis comprises of five chapters which are introduction, literature review, methodology, results and discussions, and conclusions. The outline of the thesis is as follows;

Chapter two explores previous studies in the literature on polymeric insulators with specific focus on PP and EPDM, nanofillers and the dielectric strength of insulating material. This chapter also encompasses reviews of related papers pertaining to previous research in the area.

Chapter three presents the research methodology. This chapter explained the samples preparation of PP/EPDM with and without nanofiller, the experimental test setup and procedures of breakdown voltage measurement, relative permittivity (dielectric constant), resistance and erosion to tracking, contact angle and thermal conductivity.